Quantitative Analysis of Motion and Musical Characteristics of Bon Odori Dances in Akita Prefecture

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In this study, we investigate the Bon Odori dances of Akita Prefecture, Japan, from the viewpoints of motion analysis and the study of music. As a first step, we focus on the rhythmic style of both the motion and musical characteristics, and investigate the dances representative of each of the northern and southern areas of Akita Prefecture. We investigate the above dances through quantitative procedures to guarantee objectivity on obtained results. In the analysis of dance motion, we use the motion capture data of the dances. As for music, we analyze the scores of the musical accompaniments of the dances. Feature quantities representing the rhythmic-style characteristics of each dance are extracted in both the motion-capture data and musical-accompaniment analyses. The obtained results suggest that the variety of the dances of the Hitoichi settlement (representative of the northern area) is shown not only in motion characteristics but also in musical characteristics. A slight clue to the cause of the complicated long performance shown in the Nishimonai settlement (representative of the southern area) was also obtained.

1. Introduction

In Akita Prefecture, Japan, many folk dances have been passed down. In particular, *Bon Odori*[*1] dances have attracted a great deal of attention. According to Ref. [1] , research activities on folk dances are grouped into three categories: motion analysis, study of music and ethnological approach. As for the *Bon Odori* dances of Akita Prefecture, Ref. [2] reported an attempt to clarify the relationship between dance motion and the folk customs of the places where the dances have been passed down, from the viewpoints of motion analysis and the ethnological approach. However, the influence of musical characteristics was not considered.

Taking the above situation into account, we investigate the *Bon Odori* dances of Akita Prefecture in this study, from the viewpoints of motion analysis and the study of music. As a first step, we focus on the rhythmic style of both the motion and musical characteristics, and investigate the dances representative of each of the northern and southern areas of Akita Prefecture.

Here, we investigate the above dances through quantitative procedures to guarantee objectivity on obtained results. In the analysis of dance motion, we use the motion capture (Mocap) data of the dances. We extract feature quantities representing the rhythmic-style characteristics of each dance [3]. As for music, we quantitatively analyze the scores of the musical accompaniments of the dances. To evaluate the rhythmic style of each accompaniment, we newly define several feature quantities.

To accurately extract the feature quantities, we must select an appropriate data description format. In this study, we do not consider the influence of difference generated on multiple performances of the same dance. Adopting a symbolized data format that does not include information on performance difference is one of the approaches to satisfy the above requirement.

In the analysis of musical accompaniments, we use symbolized five-line staff scores. This data format has often been used for the analysis of musical pieces, and its effectiveness in quantitative accuracy has been demonstrated (e.g., Ref. [4]). As for dance motion, on the other hand, there is no symbolized format that is match for the staff notation of music in quantitative accuracy. Therefore, we directly analyze Mocap data measured through actual dance performances, instead of symbolized data. To avoid the confusion between the essential motion characteristics of a dance and characteristics peculiar only to specific performances, we prepare multiple data streams for a single dance.

2. *Bon Odori* Dances of Akita Prefecture

2.1 Grouping of *Bon Odori* Dances

According to Ref. [5], the *Bon Odori* dances of Akita Prefecture are grouped into four systems as shown in **Fig. 1**. This grouping was proposed based on the condition of the dances in 1937. However, most of the dances of the *Yuri-Bon-Odori* System have been lost until now [6]. In addition, the area of

*1 *Bon Odori* is a type of Japanese folk dance performed during the annual Buddhist festival called *O-Bon* (or simply *Bon*).

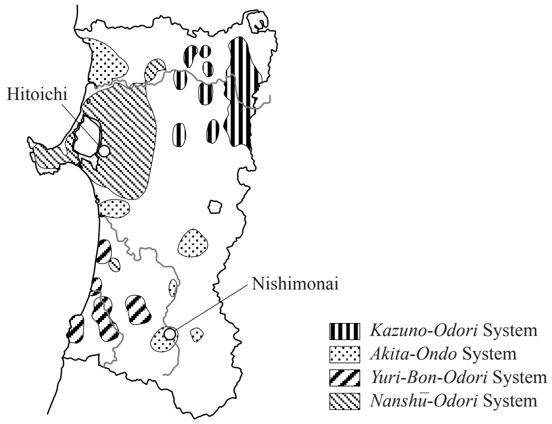

Fig. 1 Distribution of *Bon Odori* systems in Akita Prefecture (created by tracing the map in Page 17 of Ref. [2]).

Table 1 *Bon Odori* dances passed down in the Hitoichi and Nishimonai settlements.

Settlement	Dance	Mocap data*		Musical accompaniment	
		No.	Length [s]**	Tempo#	Part
Hitoichi	*Dendenzuku*	3	6.6	176 - 184	B flute## Drum
	Kitasaka	4	5.5	144	B flute## Drum
	Sankatsu	4	11.6	126 - 132	B flute## Drum
Nishimonai	*Ondo*	3	44.5	72	B flute## Shamisen### Drum Gong
	Ganke	3	41.1	116	B flute## Drum Gong

* : Provided by Warabi-za Co., Ltd.
Sensor system:
MotionStar Wireless (Ascension Technology Corporation, frame rate: 30 fps) for the dances of Hitoichi.
MotionStar Wireless with LIBERTY (Polhemus)×2 (frame rate: 30 fps) for the dances of Nishimonai.
** : Mean value of the motion-capture data streams used in the analysis.
\# : Number of quarter notes per minute.
\#\# : Bamboo flute (transverse flute).
\#\#\#: Three-stringed Japanese traditional instrument.

the *Kazuno-Odori* System was not included in the territory of Akita Domain in the early-modern times when *Bon Odori* spread around the country [2]. Therefore, we select the dances of the two settlements Hitoichi and Nishimonai, which belong to the *Nanshū-Odori* (i.e., northern-area) and *Akita-Ondo* (i.e., southern-area) Systems, respectively, as shown in Fig. 1. The dances of the above two settlements have been regarded as the constituents of the top three *Bon Odori* dances in Akita Prefecture [3].

2.2 Motion Capture Data

Table 1 shows the selected dances. The Mocap data of the dances are those measured by using magnetic Mocap systems. The measured raw data were converted into those giving the motion of a skeleton with a predetermined structure (i.e., with eighteen body segments, the method of Ref. [7] was used for conversion). The above conversion allows us to represent the state of body motion systematically with a skeletal structure.

It is noted in Table 1 that the performance lengths of the dances of the Nishimonai settlement are much longer than those of the Hitoichi settlement. According to the suggestion in Ref. [8], the dances of Nishimonai were affected by the professional dancers who performed in the amusement quarter of the Innai Silver Mine[*2] in the early-modern times. Ref. [8] pointed out that their sophisticated dancing style may have caused the complicated long performance length of the dances of the Nishimonai settlement, which was connected to the Innai Silver Mine by the Omono-River water route.

2.3 Musical Accompaniment

The information on the musical accompaniments of the dances is also shown in Table 1. The parameters of the accompaniments are those extracted from the transcribed scores presented in Ref. [5]. The above scores are used in the actual musical-accompaniment analysis described in Section 5. One can recognize in Table 1 that the numbers of parts in the dances of the Nishimonai settlement are larger than those of the Hitoichi settlement. This is thought to have been caused by the influence of the performance style of the professional dancers in the Innai Silver Mine, as with the case of the long performance length mentioned in Section 2.2.

3. Analysis of Motion Characteristics

In the analysis of motion characteristics, two rhythmic-style feature quantities (beat intensity and rhythm complexity) are calculated at every Mocap data stream by the method of Ref. [3] as shown below.

First, the whole-body motion-speed data stream is obtained from the temporal variation of the positions of the principal joints (shoulders, elbows, wrists, fingers, hips, knees, ankles, toes, waist, neck and head, including end effectors) as follows:

$$v(n) = \frac{\sqrt{\sum_{j=1}^{J} \sum_{\gamma=x,y,z} \{p_{j,\gamma}(n+1) - p_{j,\gamma}(n)\}^2}}{\Delta t} \quad (1)$$

*2 The Innai Silver Mine is a silver mine developed in the early-modern times, and located in the place along Omono River upstream from the Nishimonai settlement. Its amusement quarter attracted many professional dancers as the mine prospered [8].

where $p_{j,\gamma}(n)$ (γ: x, y or z) is the γ-coordinate of the jth joint at the nth frame (coordinate system: fixed to the pelvis), J is the number of the principal joints taken into account ($J = 19$) and Δt is the sampling time, respectively. The time-series data stream of $p_{j,\gamma}(n)$ are filtered to eliminate jitter (by using a Gaussian filter, cut-off frequency: 9.0 Hz), and normalized by the body height to reduce the influence of differences in physical constitution.

Next, the feature quantity characterizing beat intensity, q_{BI}, is calculated by using $v(n)$:

$$q_{\mathrm{BI}} = \frac{1}{2}\log\frac{\sum_{n=1}^{N}\{v(n) - v_0(n)\}^2}{N} - A\log(\tau\Delta t) \quad (2)$$

where τ is the frame number giving the first positive peak of the autocorrelation of $v(n)$, $v_0(n)$ is the moving average of $v(n)$ (moving average time: τ), N is the total number of frames and A is the weighting coefficient to the beat-interval element $\tau\Delta t$ (set as $A = 0.3$), respectively. The first term of Eq. (2) corresponds to the motion-speed variation based on the moving-average value, and gives the strength of motion-speed surges that induce beats. On the other hand, the second term corresponds to the pace of tempo in dance motion because the value of $\tau\Delta t$ gives the period of the periodic variation of $v(n)$. As a result, the greater the motion-speed variation or the faster the tempo, the larger the value of q_{BI}.

Another feature quantity characterizing rhythm complexity, q_{RC}, is obtained by using the value of approximate entropy [9, 10] as follows:

$$\boldsymbol{\mu}(n) = [v(n) \quad v(n+\tau') \quad \cdots \quad v(n+(m-1)\tau')]^{\mathrm{T}}$$

$$d(\boldsymbol{\mu}(n), \boldsymbol{\mu}(j)) = \max_{k=1,2,\cdots,m}(|v(n+(k-1)\tau') - v(j+(k-1)\tau')|)$$

$$C_n^m = \frac{\sum_{j=1}^{N-(m-1)\tau'}\theta(r - d(\boldsymbol{\mu}(n), \boldsymbol{\mu}(j)))}{N-(m-1)\tau'}$$

$$\Phi^m = \frac{\sum_{n=1}^{N-(m-1)\tau'}\log C_n^m}{N-(m-1)\tau'}$$

$$q_{\mathrm{RC}} = \Phi^m - \Phi^{m+1} \quad (3)$$

where τ'=round(0.2τ), $m = 4$, $r = 0.5\times$(standard deviation of $v(n)$) and $\theta(x)$ is the Heaviside function, respectively. The value of q_{RC} becomes large when $v(n)$ shows a complex and irregular waveform. In actual calculations, we use a fast algorithm [11] to reduce the calculation time.

4. Analysis of Musical Accompaniment

In the analysis of musical accompaniment, two rhythmic-style feature quantities (between-part distance and mean note length) newly defined are calculated at every accompaniment score as shown below.

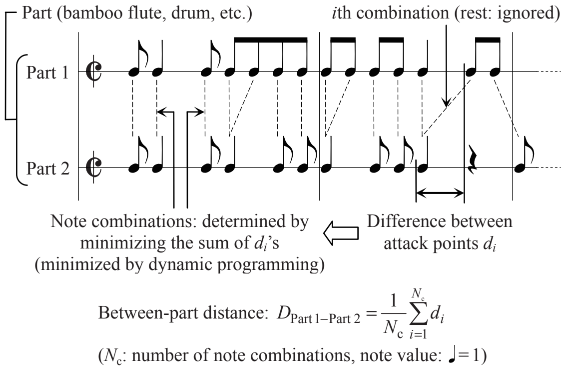

Fig. 2 Derivation of the between-part distance in musical-accompaniment analysis.

As shown in Table 1, all the musical accompaniments analyzed in this study have multiple parts. In Ref. [4], a musical piece having multiple parts was effectively characterized by analyzing the situation of matching between parts. Referring to the above approach, we define feature quantities as follows.

The first quantity is the between-part distance that quantifies the degree of matching between two parts. In the calculation of this quantity, each of the notes in a part is first combined with a note included in another part. A note nearest to the former note is selected as the latter note. Each of the unselected notes in the latter part is then combined with the nearest note in the former part. As a result, each of all the notes included in the above two parts is combined with another note as shown in **Fig. 2** (rests are ignored in this process). To automatically determine the pattern of all combinations, we define the cost function f:

$$f = \sum_{i=1}^{N_{\mathrm{c}}} d_i \quad (4)$$

where N_{c} is the number of combinations and d_i is the absolute value of the difference between the attack points of the notes of the ith combination, respectively. f is automatically minimized by a dynamic-programming technique [12]. Finally, the between-part distance, $D_{\mathrm{Part\,1-Part\,2}}$, is calculated as follows:

$$D_{\mathrm{Part\,1-Part\,2}} = \frac{1}{N_{\mathrm{c}}}\sum_{i=1}^{N_{\mathrm{c}}} d_i \quad (5)$$

This quantity is calculated at every part pair. According to Ref. [4], the larger the $D_{\mathrm{Part\,1-Part\,2}}$ value, the "wider" the part pair (otherwise, the "thicker" the part pair).

The second quantity is the mean note length that gives information on the tempo of each part pair:

$$L_{\text{Part 1–Part 2}} = \min\left(\frac{60}{N_1 n_1}\sum_{i=1}^{N_1} l_{1,i},\ \frac{60}{N_2 n_2}\sum_{j=1}^{N_2} l_{2,j} \right) \tag{6}$$

where N_1 and N_2 are the numbers of notes in Parts 1 and 2, n_1 and n_2 are the numbers of quarter notes per minute in Parts 1 and 2[*3], $l_{1,i}$ is the note value of the ith note of Part 1 and $l_{2,j}$ is that of the jth note of Part 2, respectively. Eq. (6) gives the $L_{\text{Part1–Part2}}$ value in seconds. This quantity is calculated at every part pair to make it possible to plot each pair in the $D_{\text{Part 1–Part 2}} - L_{\text{Part 1–Part 2}}$ scatter plot. The shorter the $L_{\text{Part 1–Part 2}}$ value, the faster the tempo.

5. Results and Discussion

5.1 Motion-capture Data Analysis

Figure 3 shows the rhythmic-style distribution of the Mocap data streams. It is noted that the dances of Hitoichi spread widely from the *Mild* region to the *Intense* region. According to the oral tradition passed down in the Hitoichi settlement, the *Bon Odori* dances of this settlement had originally consisted of two fast-tempo dances (i.e., *Dendenzuku* and *Kitasaka*), and *Sankatsu* having a graceful slow tempo was later introduced from outside [13]. As previously confirmed in Ref. [3], the tendency of the beat intensity obtained from the Mocap data is almost consistent with this oral tradition.

As for the Nishimonai settlement, the dances converged on the *Mild-Complex* region. As mentioned in Section 2.2, the dancing style of this settlement is thought to have been affected by that of the professional dancers who performed in the Innai Silver Mine. This might have given rise to the convergence on the *Complex* region. On the other hand, the convergence on the *Mild* region is thought to be caused by the slowness of tempo relative to the fast tempo of *Dendenzuku* and *Sankatsu* passed down in the Hitoichi settlement.

5.2 Musical-accompaniment Analysis

Figure 4 shows the rhythmic-style distribution of the part pairs in the musical accompaniments of the dances. One can recognize in Fig. 4 that the part pairs of the Hitoichi settlement were separated into two groups (i.e., the dance sets {*Dendenzuku*, *Kitasaka*} and {*Sankatsu*}). As mentioned in Section 5.1 , the set {*Dendenzuku*, *Kitasaka*} is thought to have its origin different from that of the set {*Sankatsu*}. The obtained results may reflect the above difference.

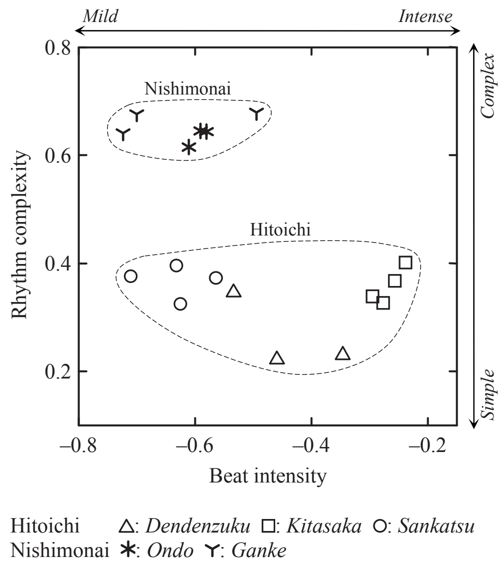

Fig. 3 Rhythmic-style distribution obtained by motion-capture data analysis.

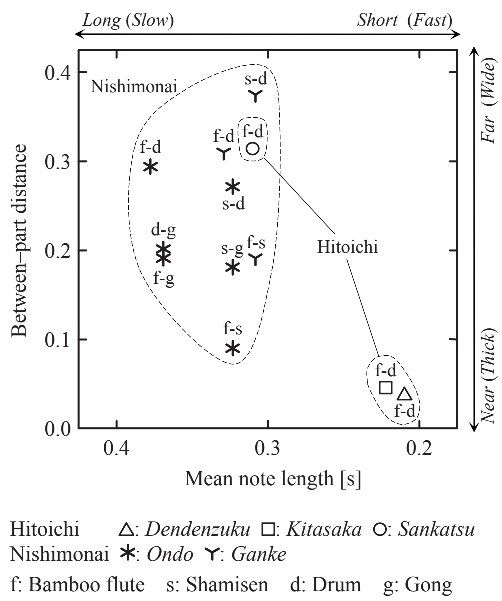

Fig. 4 Rhythmic-style distribution obtained by musical-accompaniment analysis.

On the other hand, the part pairs of the Nishimonai settlement formed a cluster in the *Slow-Wide* region. Although the area of this cluster is large relative to those of the dance sets of the Hitoichi settlement, the constituents of the Nishimonai settlement can be regarded as forming only a single group. As mentioned in Section 5.1, the Mocap data of the dances of this settlement converged on a single region. The distribution obtained from the analysis of musical accompaniment showed a similar tendency.

*3 In the case that the value of the number of quarter notes per minute is specified in a particular range (e.g., *Dendenzuku* and *Sankatsu* in Table 1), the central value of the range is used in Eq. (6).

Table 2 Statistics of rhythmic-style distribution.

Stat.	Hitoichi				Nishimonai			
	BI	RC	BPD	MNL	BI	RC	BPD	MNL
Mean	-0.449	0.337	0.132	0.247	-0.617	0.650	0.217	0.340
SD	0.165	0.057	0.129	0.045	0.077	0.022	0.068	0.025

BI: Beat intensity, RC: Rhythm complexity,
BPD: Between-part distance, MNL: Mean note length (in seconds).

In the Nishimonai cluster, the part pairs of the bamboo-flute-shamisen combination were located in the bottom of each of *Ondo* and *Ganke*, i.e., in the *Thick* region, whereas those of the bamboo-flute-drum and shamisen-drum combinations were located in the *Wide* region. This means that the bamboo-flute and shamisen parts play melodies almost synchronized with each other, whereas the drum part plays the rhythmic part having a sequence different from that of the bamboo-flute and shamisen parts.

5.3 Discussion

The analysis results of both the motion and musical characteristics provided the same tendency, namely the spread of the dances of the Hitoichi settlement and the convergence of those of the Nishimonai settlement. **Table 2** shows the statistics of the feature quantities (mean and standard deviation) obtained at every settlement. It is noted that all the standard deviations of Hitoichi show values about two times larger than those of Nishimonai. As a result, the above tendency is quantitatively substantiated. The motion-characteristic variety of the *Bon Odori* dances of the Hitoichi settlement was previously pointed out in Ref. [3]. The obtained results suggest that the variety of Hitoichi is seen not only in motion characteristics but also in musical characteristics.

The Hitoichi settlement is located in the Kōtō Area that includes the region of the eastern coast of Hachirōgata Lagoon [8]. According to Ref. [8], the motion-characteristic variety of the Kōtō Area is attributed to the influx of human resources and articles in the medieval and early-modern times from the regions other than Akita Prefecture. This is thought to have brought about a cultural variety in the Kōtō Area, and might have caused the diversity of both the motion and musical characteristics of the *Bon Odori* dances of the Hitoichi settlement.

As already mentioned, on the other hand, the *Bon Odori* dances of Nishimonai were affected by the professional dancers who performed in the amusement quarter of the Innai Silver Mine. The complicated long performance and increase in the number of musical parts seen in these dances are thought to have been caused by the above influence. However, the diversification of characteristics in a set of multiple dances, such as the case of the Hitoichi settlement, is not seen in the Nishimonai settlement. The cause of the lack of diversification in this area is unclear in the present stage.

6. Conclusion

In this study, we have investigated the motion and musical characteristics of the *Bon Odori* dances of Akita Prefecture, and their distribution has been clarified to a certain extent. However, there still remain some unresolved issues, such as the cause of the lack of diversity in the Nishimonai settlement. Additional work is needed to address the issues. To investigate the relevance to the regional culture, e.g., the folk customs passed down in each area, will also be the subject of future work.

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